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THE BEHAVIOR AND DISSOLUTION OF GAS BUBBLE
CLOUDS IN AN OCEAN ENVIRONMENT



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**THE BEHAVIOR AND DISSOLUTION OF GAS BUBBLE
CLOUDS IN AN OCEAN ENVIRONMENT**

A Trident Scholar Report

by

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ABSTRACT

This paper entails a study of the absorption process of carbon dioxide into both fresh water and seawater. The project investigated the factors which affect the dissolution of CO_2 . These include the concentration gradient between the gas bubble and water, the relative velocity of the bubble with respect to the water, the combined surface area of carbon dioxide bubbles in contact with the water, the salinity of the water, the temperature of the water, and the pressure of the water. The effect of temperature and pressure were not investigated due to time constraints. A six foot plexiglass tower was used to create a water column through which the gas bubbles were percolated. The pH change of the water was measured at both the inlet and outlet of the tower. The amount of dissolved gas was determined by using the first dissociation constant and the concentration of H^+ ions in the water. Three series of data were taken. The first two involved percolating first, pure carbon dioxide at various flow rates, then an O_2 and CO_2 mixture through fresh water. The first series of tests proved that high flow rates developed the highest concentrations of CO_2 with a maximum of 0.00045 moles/liter. The last series of tests involved testing the absorption rate in waters of various salinities. These tests showed much higher concentrations of CO_2 up to 0.0011 moles/liter. Overall, it was found that water has the capability to CO_2 and further study in this field is recommended.

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NOMENCLATURE

C_T	Total dissolved gas
D	Diffusion constant
K	Hydration constant
K_D	Distribution constant
K_H	Henry's law constant
K_1	First dissociation constant
K_2	Second dissociation constant
P_{CO_2}	Partial pressure of carbon dioxide
R	Universal gas constant
T	Absolute temperature
U_B	Relative bubble velocity
α_0	Ionization fraction for $[H_2CO_3^*]$
α_1	Ionization fraction for $[HCO_3^-]$
α_2	Ionization fraction for $[CO_3^{2-}]$
δ	Diffusion layer thickness

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INTRODUCTION

The dissolution process of gas bubbles into a liquid solution has long been a topic of interest for engineers and scientists alike. The applications of this phenomenon are common throughout science and industry. The makers of carbonated drinks use bubble absorption to give soda its fizz. Naval engineers are interested in the bubble dissolution rates which govern the persistence of a ship wake. The bubble dissolving phenomenon has long been used in pollution control processes to scrub liquid solutions of gases, aerate or deaerate water, and promote biological activity. These examples show the diversity to which gas absorption is used today.

A large potential exists for the dissolution of carbon dioxide into seawater because of the low concentration of dissolved CO_2 present in natural waters. In the ocean, carbon dioxide is continually absorbed from the atmosphere and marine animal life. The dissolved gas dissociates to form a weak acid which provides a buffer for many of the mineral bases present in the ocean. Many of the precipitates which form in seawater are carbonates or are derived from dissolved CO_2 . The possibility of utilizing seawater's natural absorption capabilities provides the motivation for investigating the factors which affect the dissolution potential.

The primary interest ocean engineers have in seawater's

ability to absorb CO_2 relates to the possibility of using seawater to design a gas scrubber for underwater habitats. The problem with recycling the air in life support systems is that carbon dioxide builds up as respiration occurs. Before the concentration of CO_2 reaches toxic levels, it must be removed or "scrubbed" from the atmosphere. Currently, existing habitats must rely on expensive processes such as chemical filtering through lithium hydroxide and regeneration cycles to remove carbon dioxide from the breathing gas. If seawater can remove the necessary amounts of carbon dioxide, than this might provide a less costly alternative than the current available systems.

Another possible use of seawater as a scrubber is to cleanse the exhaust of an underwater air-breathing engine. The primary products of combustion include water and carbon dioxide in addition to air and all the unburned gases. If scrubbing is used to reduce the carbon dioxide, the exhaust gas could be reused.

One of the current environmental concerns is the "greenhouse effect." This is a global warming trend caused by increased levels of carbon dioxide in the atmosphere. This build-up of CO_2 would change the concentrations of carbon dioxide present in the ambient air. If this is the case, then the interface between the atmosphere and the ocean's surface certainly warrants investigation. These examples emphasize the need to learn more about the

absorbption of carbon dioxide in water and what factors would optimize this process.

This study investigated the factors that influence the dissolution of carbon dioxide in water. The primary factors that affect carbon dioxide dissolution are the partial pressure of CO_2 within the gas bubble relative to the surrounding ambient CO_2 concentration in the water, the relative velocity of the bubble to the surrounding fluid, the quantity of carbon dioxide in contact with the water, the salinity of the water, the temperature of the water, and the ambient pressure of the water solution. Gas mixtures were filtered through a column of water to obtain data. The water was monitored to determine how much carbon dioxide was absorbed into the liquid.

Although the report covers some of theory behind gas dissolution, the primary emphasis has been in obtaining experimental data. This paper covers the design and operation of a seawater column used to obtain information on the dissolution of carbon dioxide in water. It also steps through the data reduction and analysis leading into the conclusions of the work. An outline of future work which could be investigated is also enclosed.

THEORY

To verify the lab results, the processes which drive carbon dioxide absorption in water were investigated. The primary focus of the theoretical background review was divided into three main topics: the concentration gradient and Henry's law; the chemical breakdown of dissolved carbon dioxide; and a study of the transfer of gas through the diffusion layer as ruled by Fick's law. Aquatic Chemistry by Strumm and Morgan and Equilibria, Nonequilibria, and Natural Waters by Pytkowicz were the primary sources.

A difference in concentration drives the dissolution of a carbon dioxide gas bubble. The concentration of carbon dioxide in the gas bubble may be much higher than the concentration of carbon dioxide dissolved in the surrounding water. Thus, as nature strives to obtain an equilibrium, the carbon dioxide crosses the gas-water interface and enters into solution. Henry's law is used to determine the concentration of CO_2 inside the bubble. The naturally occurring concentration of carbon dioxide in the water outside the bubble is usually very small. This concentration difference drives the rate of the reaction. Henry's law relies on two separate equations to develop a relationship between the concentration of gas in the water and the partial pressure of carbon dioxide in the bubble:

Distribution constant (mass law), K_D :

$$K_D = \frac{[CO_{2(aq)}]}{[CO_{2(g)}]} \quad (1)$$

and Dalton's law of partial pressure:

$$[CO_{2(g)}] = \frac{P_{CO_2}}{RT} \quad (2)$$

Where the partial pressure of CO_2 is determined by the volume fraction of the CO_2 gas with respect to the other gases present in the bubble. The water vapor pressure must also be accounted for in the partial pressure. When equation (2) is substituted into the first equation, an expression can be obtained for Henry's law constant, K_H :

$$[CO_{2(aq)}] = K_H P_{CO_2} \quad (3)$$

where

$$K_H = \frac{K_D}{RT} \quad (4)$$

Using equation (3) and a value for K_H which corresponds to the temperature of the water, the equilibrium concentration for dissolved carbon dioxide on the inside surface of the bubble can be calculated.

It can be determined that changes in the pH of the water reflect the amount of carbon dioxide absorbed. To do this, it becomes necessary to review the chemical reactions that occur in the water. After the carbon dioxide gas enters the water it goes through a series of reactions:



The first reaction is controlled by Henry's law and has an equilibrium constant equal to K_H , Henry's law constant. The other equilibrium constants are defined by the following series of equations:

$$[H_2CO_3^*] = [CO_2(aq)] + [H_2CO_3] \quad (5)$$

$$\frac{[CO_2(aq)]}{[H_2CO_3]} = K \quad (6)$$

$$\frac{[H^+][HCO_3^-]}{[H_2CO_3]} = K_1 \quad (7)$$

$$\frac{[H^+][HCO_3^-]}{[H_2CO_3]} = K_{H_2CO_3} \quad (8)$$

$$\frac{[H^+][CO_3^{2-}]}{[HCO_3^-]} = K_2 \quad (9)$$

The equilibrium constants are functions of temperature and salinity. Numerous experiments have been conducted to find K_1 and K_2 at different temperatures and salinities. The

values used for analyzing the test data were obtained from data tables found on pages 149 & 150 in Aquatic Chemistry based on data collected by H. S. Harned and R. Davies, Jr. in 1943 (Stumm, Morgan, 1970). The average value for K is very high with $[H_2CO_3]$ often resulting in less than 0.3% of $[H_2CO_3^*]$ (Pytkowicz, 1983). This demonstrates that $[CO_2(aq)] \gg [H_2CO_3]$ which validates the assumption that $[H_2CO_3^*] = [CO_2(aq)]$. The equilibrium constants can be used to determine the concentration condition and the ionization fractions:

$$C_T = [H_2CO_3^*] + [HCO_3^-] + [CO_3^{2-}] \quad (10)$$

$$[H_2CO_3^*] = C_T \alpha_0, [HCO_3^-] = C_T \alpha_1, [CO_3^{2-}] = C_T \alpha_2 \quad (11)$$

Calculating the ionization fractions for a low pH proves that $[H_2CO_3^*]$ will dominate equation (10). This proves that most of the dissolved carbon dioxide still exists as either $[CO_2(aq)]$ or $[H_2CO_3]$. Since very little of the carbon dioxide was hydrated, most of the dissolved gas remained in its aqueous form. Thus, the concentration of hydrogen produced from the first dissociation, equation (7), is the predominant source of hydrogen ions in the water. Since the pH is defined as $-\log [H^+]$, by monitoring pH one can calculate how $[H^+]$ changes which reflects the amount of CO_2 absorbed in the water.

For a gas bubble to dissolve in the water, gas molecules must pass through the gas-water interface. Before the

carbon dioxide molecules can diffuse into the solution, they must pass through a thin layer of water surrounding the bubble that has a higher concentration of carbon dioxide than that of the ambient solution. This film of increased $[\text{CO}_2]$ tends to resist the diffusional flow of carbon dioxide gas molecules. This occurs because the concentration gradient from the bubble to the diffusional layer is lower than the gradient which would exist between the bubble and the ambient solution. Since the gas molecules must cross this diffusional layer, its thickness is important in mass transfer considerations. Figure 1 shows the development of the diffusion layer around the surface of the bubble.

Because of the amount of time required for the carbon dioxide to hydrate, very little breakdown of the gas occurs in this boundary layer. The diffusion process is driven by Henry's law and the gas is transferred across the diffusion layer into the general solution. This gas flux is controlled by Fick's law. The governing factors of the diffusion rate are the relative velocity of the bubble with respect to the water, U_b , the concentration gradient in the diffusion layer, δ , and the CO_2 /water diffusion constant, D . These factors are related in the following equation:

$$U_b \frac{\partial C}{r \partial \theta} = D \frac{\partial^2 C}{\partial r^2} \quad (12)$$

The following boundary conditions exist for the above dif-

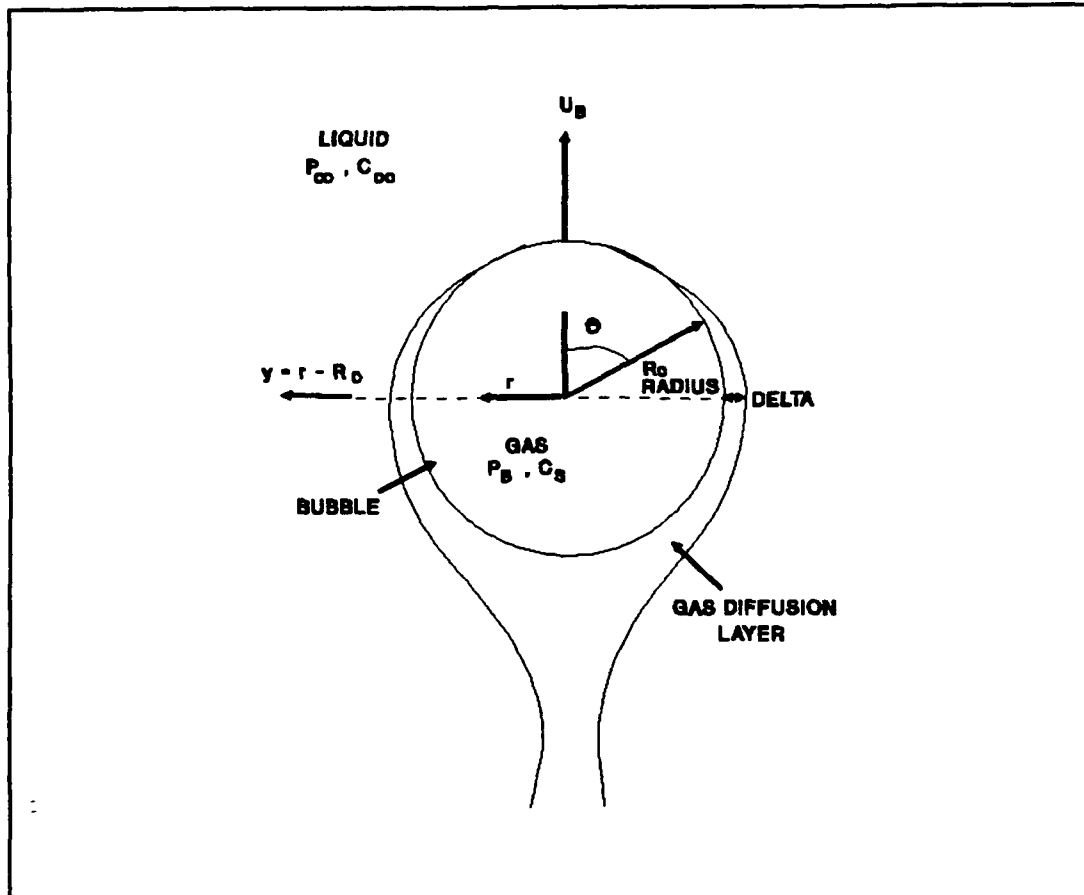


Figure 1 Bubble Configuration (Cerza, et. al., 1990)

ferential equation:

$$r=R_0, C=K_H P_{CO_2} \quad 1)$$

$$r=\infty, C=C_\infty \quad 2)$$

The diffusion process is symmetrical 3)

Using these boundary conditions, a value for the mass flux can be obtained by integrating across the surface of the bubble:

$$\frac{dm}{dt} = D \int_0^A \left(\frac{\partial C}{\partial r} \right)_{r=R_0} dA \quad (13)$$

where A is equal to the surface area of the bubble. It must be noted that, although these equations are important for understanding what controls the dissolution process, they were not used for verifying the results. To do so would have required expanding the model from a single bubble to an entire bubble cloud and calculating what type of interference occurs between two closely dissolving bubbles. Time constraints prevented the construction of this analytical model.

EXPERIMENTAL APPARATUS

The experimental apparatus used in this project provided an interface where a gas exchange occurred between the bubble clouds and the water. The water flowed through a six foot plexiglass tower at a constant velocity. A constant velocity was maintained by keeping the water height inside the tank constant throughout the flow process. The gas flow was introduced into the tower near the bottom of the water column to allow for significant contact time between the gas and the water as the bubbles rise to the water surface. In addition to monitoring the gas and water flow rate, a method of determining the amount of carbon dioxide absorbed must be



Figure 2 Experimental Apparatus used for this Project

determined. Figure 2 depicts the actual equipment used for this project. This section will concentrate on four main topics: the gas exchanger, the water supply system, the gas delivery system, and the process for monitoring absorption.

The gas exchanger used in this experiment was a six foot plexiglass tower with an eight inch brass extension included on the bottom. The cross sectional dimensions on the tower are 7" X 7" which created a square column of water with an area of 49 square inches. The height of the water column was 74 inches which allowed for a total water volume of 3,626 cubic inches or 15.7 U.S. gallons. The gas was introduced 16 inches above the bottom end plate of the tower and flowed upwards through the descending water flow field. If the gas inlet were placed too close to the bottom drain, the liquid stream lines would converge and not be uniformly spaced and aligned in the direction of the downward water flow. In the current configuration, the bubbles rose up the tower counter to the water flow. At the bottom of the tower, there was a removable brass plate. There were two penetrations in the bottom plate. One opening allowed the gas line to extend up to its outlet, while the second was an opening for the drain. A schematic of the system is provided in Figure 3.

The water which was used for this project came from the tap in the basement of Rickover Hall. This water was channeled into a 55 gallon container where it was allowed to sit

to create uniform water properties. To transport the water to the top of the tower, a 1/4 h.p. pump was used. The water lines were composed of 3/8" inner diameter copper tubing. There was a flow control valve included in the water line, but, because the flow produced by the pump was

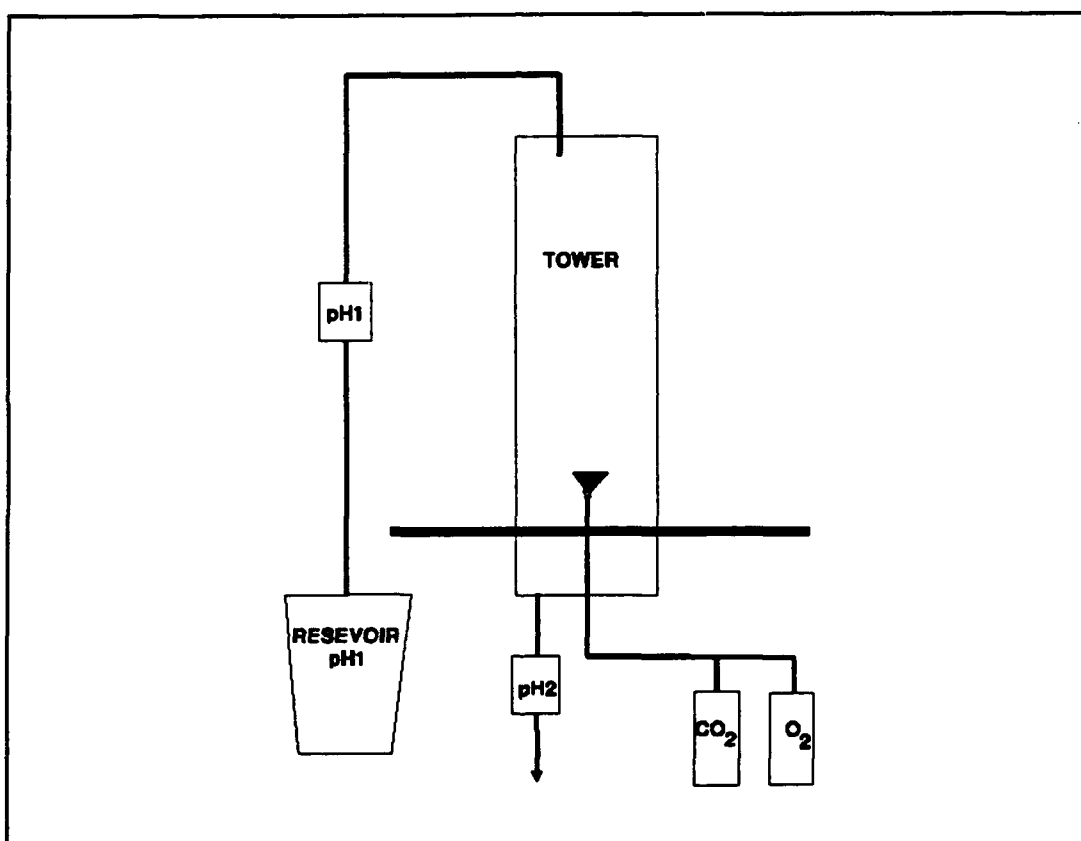


Figure 3 Layout of the Tower and all Supporting Systems

slow, this valve was never used. The tower was allowed to drain naturally using gravity to push the water out of the tower. The outlet water was routed to a waste water drain located in the floor of the room. In order to maintain a constant height of the water column, the outlet was designed to allow a higher flow rate than the inlet. A flexible

piece of 1/2" tygon tubing was used to connect the bottom plate penetration to the floor drain. Before the water could exit the system, it passed through a control valve and a flow meter. The control valve was used to match the

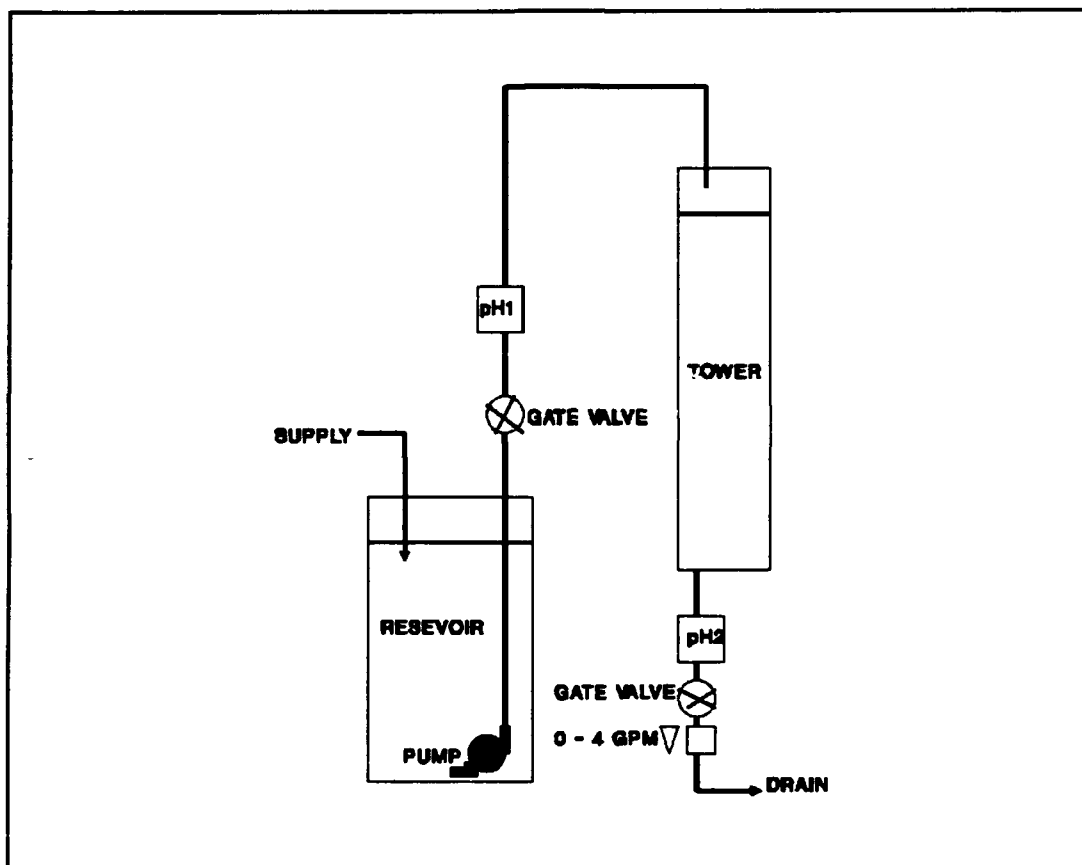


Figure 4 Schematic of the Water Supply System

outlet flow rate with the supply flow rate in order to keep the water column at a constant height. A schematic of the water supply system is shown in Figure 4.

The gas delivery system provided three primary functions. The carbon dioxide and oxygen gas were supplied

by two high pressure gas storage tanks. The first task of the system involved the use of pressure regulators to reduce the pressure of the gas supplied to usable levels in the tower. This involved reducing the gas pressure down to about five or ten pounds per square inch. The system also allowed for variable gas flow rates between the CO_2 and the O_2 and the determination of the concentration of CO_2 in the mixed gas. To do this, the oxygen and carbon dioxide lines met in a mixing chamber. The mixing chamber was a cylinder ten inches long and two inches in diameter. The flow of gas into the chamber was controlled by two needle valves, one on the oxygen line and the other on the carbon dioxide. The amount of carbon dioxide in the total flow was determined by a flow meter in the carbon dioxide line. Meanwhile the total flow of gas into the tower was monitored by a second flow meter placed between the mixing chamber and the tower. A needle valve was installed near the base of the tower to ensure that water did not flow through the porous frit and foul the gas lines. If there was no gas flow, this valve remained closed. The gas was dispersed through a three inch diameter porous frit which converted the gas stream into a bubble cloud. Figure 5 depicts a schematic of this system.

The final task which the experimental apparatus had to be equipped for was the determination of how much carbon dioxide was dissolved in the water. Several methods were considered for this purpose. After reviewing the chemistry

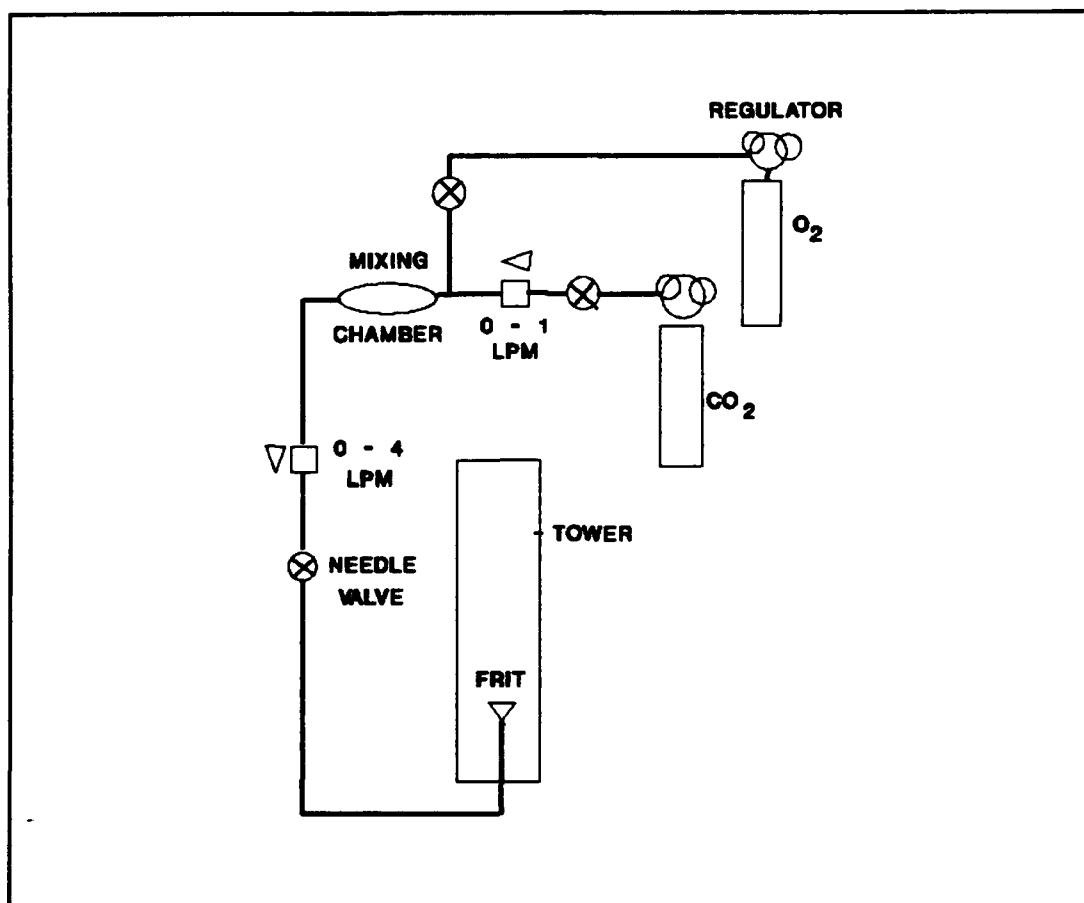


Figure 5 Schematic of the Gas Delivery System

involved with the CO_2 absorption process (see theory), it was determined that measuring the change in pH of the water between the inlet and the outlet was the most viable method. To do this, traps were built from PVC pipe and installed in both the inlet and outlet water lines. The trap housed pH probes supplied by Electro-Chemical Devices, Inc. The probes were the Model S10 Universal Sensor, which could determine the pH of the water by using an electrode that produced an electrical output in millivolts. This signal was sent to an ECD, Inc. UT21 Transmitter which converted the millivolts into milliamps, and offered signal

conditioning to keep each probe's signal safe from extraneous noise signals. The milliamp signal was then sent to a data acquisition board on a 386 computer. The milliamp reading was then stored utilizing a data acquisition program provided by Omega Engineering, Inc. The milliamps were later turned into a pH value using Quattro Pro, a procedure which will be discussed in the data analysis section.

PROCEDURE AND OBSERVATIONS

This section of the report will outline the procedure used to run each series of tests and the observations associated with the runs. Essentially, there were three sets of tests. The first group of tests involved using various gas flow rates of carbon dioxide through a freshwater column. The next set of data runs involved varying the gas mixture that was flowing through the tower. Again, freshwater was used for these tests. The final series of tests involved a constant flow of pure CO_2 flowing through waters of various salinity. Although the procedure remained similar for each test, there were some small changes which were required for each type of test conducted.

Running the experiments which only involved a variation of the carbon dioxide flow rate were the easiest tests to perform. The setup for each test was limited. It involved filling the tower with water, restoring the supply reservoir back to full, opening the CO_2 flow up to the needle valve near the base of the tower, and finally, allowing the water to settle so that the water supply had constant properties (pH, temperature, dissolved gas, etc.). The settling process involved waiting about 30 minutes to allow things to stabilize. After the water had stabilized, a thermometer was used to determine the temperature of the water reservoir. The computer data acquisition program was turned on first so that the initial absorption of the carbon dioxide

gas could be recorded. Because there is a swift change in properties during the initial contact between the gas and the water, if this step was forgotten (started late), the test was stopped and started over. In the data analysis section, it will be shown why it was so important to record that initial contact interaction. Data was sampled every ten seconds. The outlet valve was then opened and the pump was turned on. The submerged pump ran at maximum output while the drain valve was throttled to maintain a constant water column height. Once the water column was stabilized, the needle valve was slowly opened until a constant flow of CO_2 was provided. Both the gas flow and the water flow were monitored by float-type float meters. The water flow rate was dependent on the maximum output of the pump and remained at a constant rate of 4.517 liters per minute. As the test was conducted, the only things necessary to monitor were the gas flow rate and the column height.

The most noteworthy observation made during the pure carbon dioxide tests was that after 10 minutes, the only dissolution of gas occurred in the top 12 inches of the tower. This is apparent because the size of the bubbles decreased only in this region. This implies that the water column quickly approached saturation levels of $[\text{CO}_2 (\text{aq})]$ within the first 12 inches, and additional absorption only occurred when the dissolved gas hydrated, reducing the concentration. Another effect that was observed was the

quick initial drop in pH. The pH usually dropped very swiftly down to values around 5.0 and then slowly continued to drop approaching 4.8.

The only change made to the above procedure in order to conduct the mixed gas tests was to find a balance between the carbon dioxide and oxygen gas flow to create the necessary mixture inside the bubble. To do this a volumetric ratio was determined by monitoring both flow meters. The CO₂ in the mixed gas did not dissolve as thoroughly as the pure carbon dioxide bubbles. The gas bubbles scarcely diminished as they progressed to the top of the tower. This observation was verified after analyzing these data.

The last test series was designed to determine the effects that salinity have on CO₂ absorbtion. Seawater was simulated by dissolving a chemical salt known as Instant Ocean into the reservoir. The salt was added to the water as the container was filled. The solution was stirred until sufficient homogeneity was achieved. For these data trials, the water supply was limited to the amount the plastic reservoir could contain. Once the solution was mixed, the tower was filled with the salt water. A sample was obtained in order to determine the salinity of the mixture. After the tower was filled, the test was conducted in the same manner as the above procedure only using a constant flow of carbon dioxide at four liters per minute. The only variable in these tests was the salinity of the water.

One notable effect which salt had on the bubbles was the reduction in the size of the bubbles. This change was expected based on an earlier study conducted by Peltzer and Griffin (Peltzer, Griffin, 1988). As the salt concentration increased, the greater the reduction in bubble size. It also appeared that the seawater reached CO_2 saturation levels earlier than fresh water. This became evident when the bubble diameters remained relatively constant in a shorter amount of time than in the freshwater pure carbon dioxide tests. Again, dissolution seemed to occur only in the top 12 inches of the column.

DATA ANALYSIS

The information which was recorded in the datafiles by the data acquisition program was the mA values produced by the probes versus time. These measurements needed to be converted into some form of usable information. A spreadsheet was developed on Quattro Pro to convert mA first to pH values, and then to an even more usable value, the concentration of carbon dioxide in the water in moles/liter.

The first step in this process was to convert the mA readings into pH readings. The transmitter signal varied from 4 to 20 mA depending on the pH. Readings taken at both 0 and 14 pH plus several data points in the middle, confirmed that the pH probes responded linearly with a slope of 1.14 mA/pH.

The pH was converted into an $[H^+]$ using the equation:

$$[H^+] = 10^{-pH}$$

The difference in hydrogen ion concentrations was used to determine the change which occurred to the water. Since

$$[H^+]_{pH_2} > [H^+]_{pH_1}$$

$[H^+]_{pH_1}$ becomes negligible and drops out of the analysis.

The concentration of absorbed gas can be determined by using the hydrogen concentration and the first dissociation constant:

$$\frac{[H^+][HCO_3^-]}{[H_2CO_3^*]} = K_1$$

$$[H^+] = [HCO_3^{2-}]$$

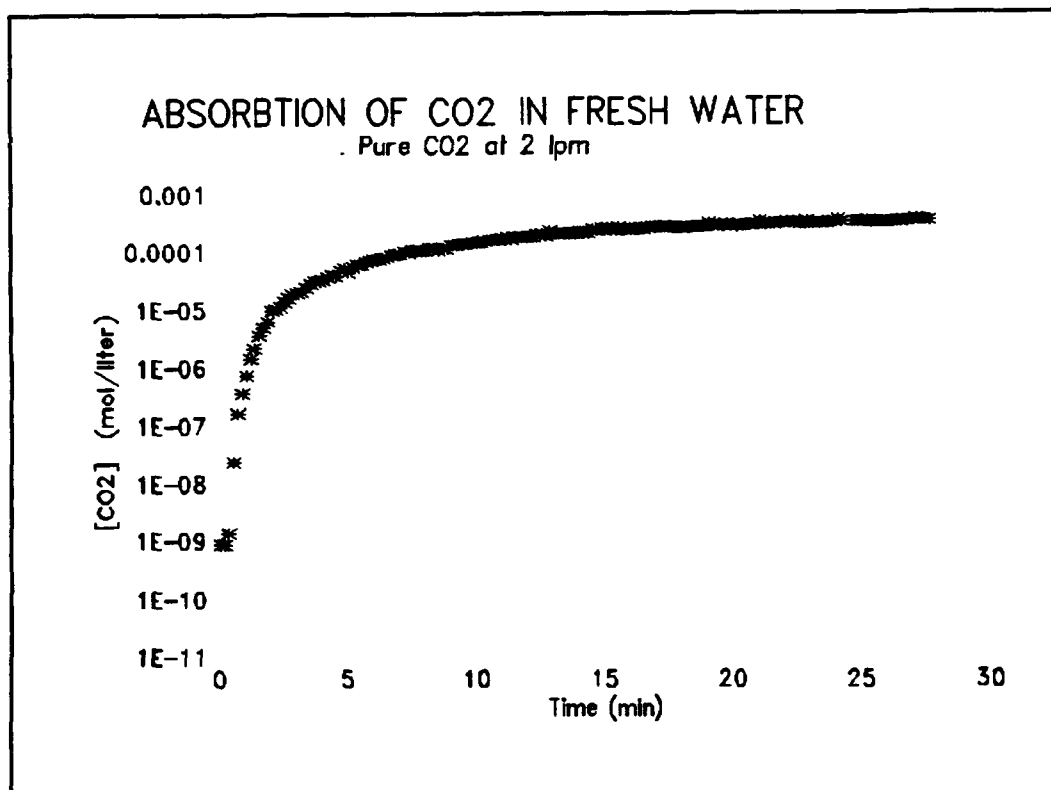


Figure 6 Curve depicting the total concentration of CO_2 , C_T , versus time

The second dissociation is not included in the analysis because the terms are small enough to be considered negligible. Thus the total amount of CO_2 absorbed in the water is:

$$C_T = [\text{H}_2\text{CO}_3^*] + [\text{HCO}_3^-]$$

with C_T in units of moles/liter.

The value for C_T was calculated for each data entry and then plotted versus time. An example of this plot is shown in Figure 6. This plot has a logarithmic ordinate to display the full range over which the concentration varied. To verify that the concentration matched the pH changes, a plot of the change in pH over time was created. Figure 7 is the

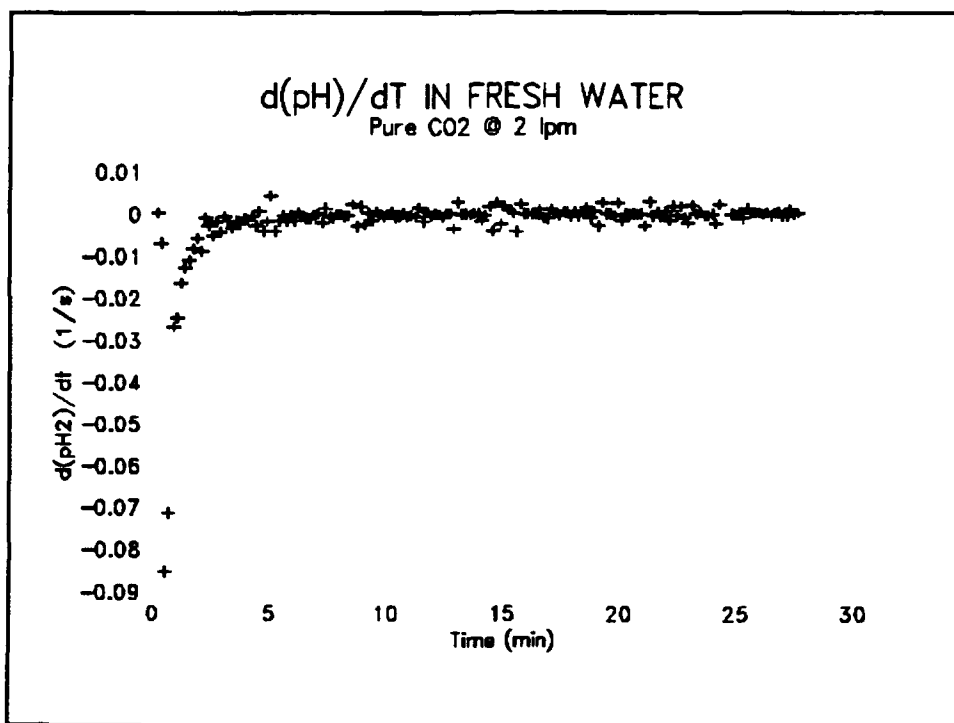


Figure 7 The Change in pH vs time

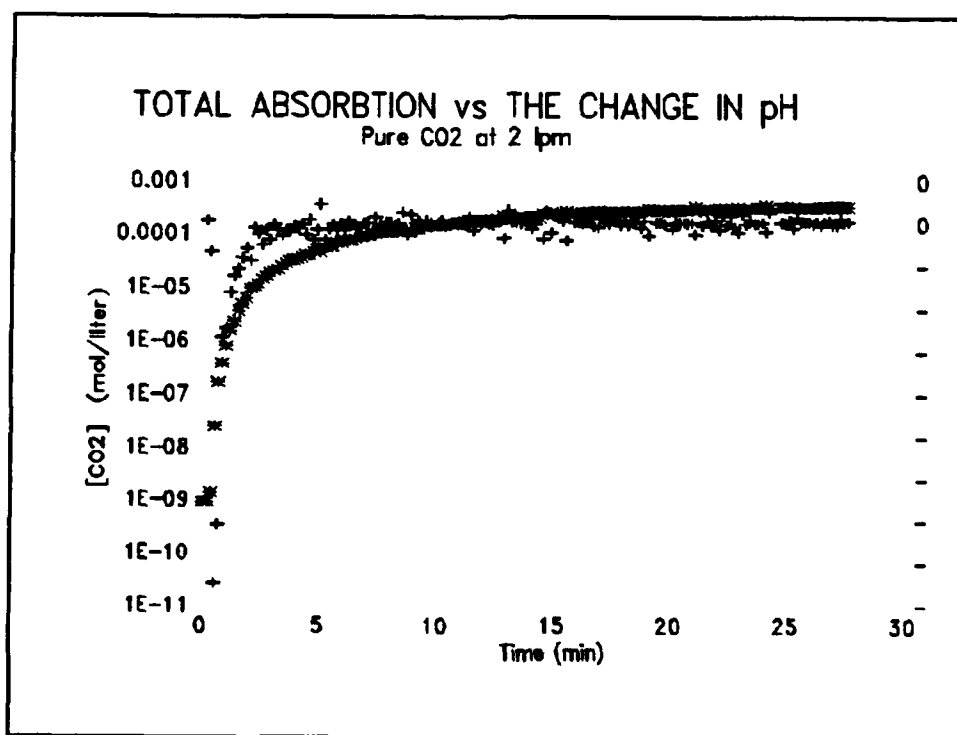


Figure 8 Graph depicting relationship between C_T and change in pH

plot of the pH change versus time. To verify that the change in pH approached zero for a steady state absorption, the curves created in Figures 6 and 7 were plotted together against time. This plot can be found in Figure 8. The basic absorption curves were plotted for the data and can be found in Appendix A.

To further simplify the data, the data from each series were plotted on one graph versus time. This was useful for determining the trends which occurred in each series. Figure 9 was used to display the effects of a varying flow rate. Figure 10 depicts the mixed gas series. The salinity data are plotted in Figure 11.

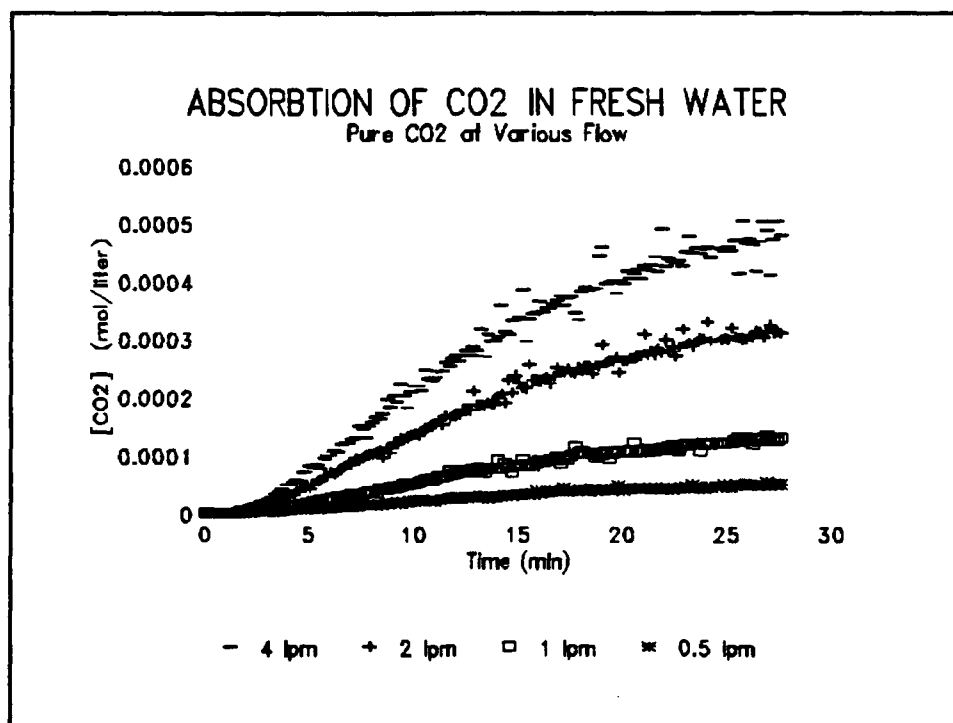


Figure 9 Comparison Between Various Gas Flow Rates of Pure CO₂ in Fresh Water

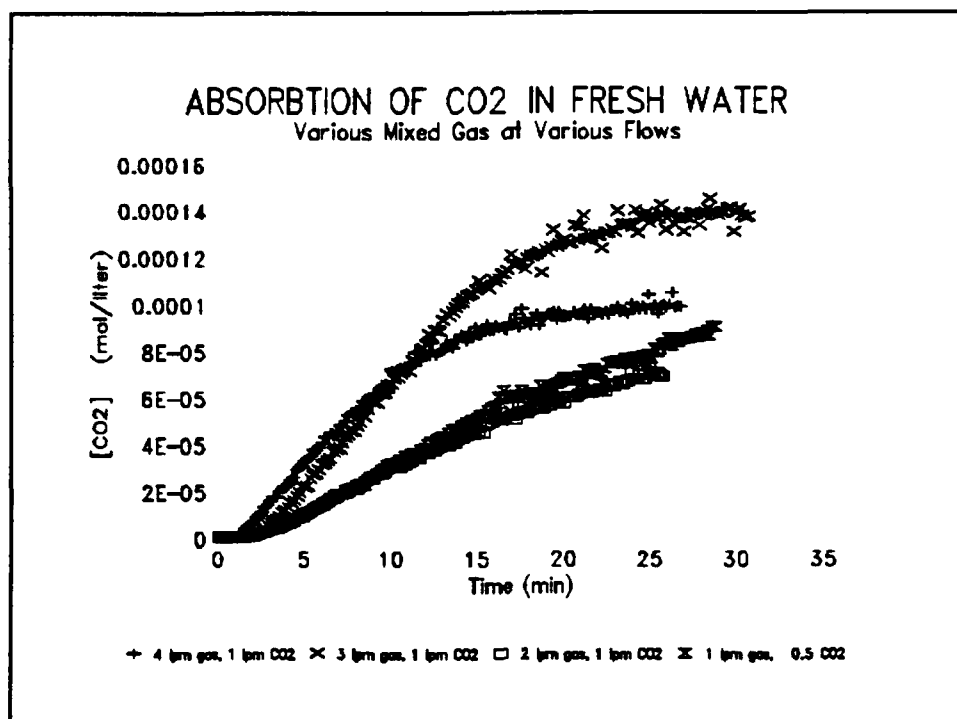


Figure 10 Comparison of Mixed Gas Concentrations in Fresh Water

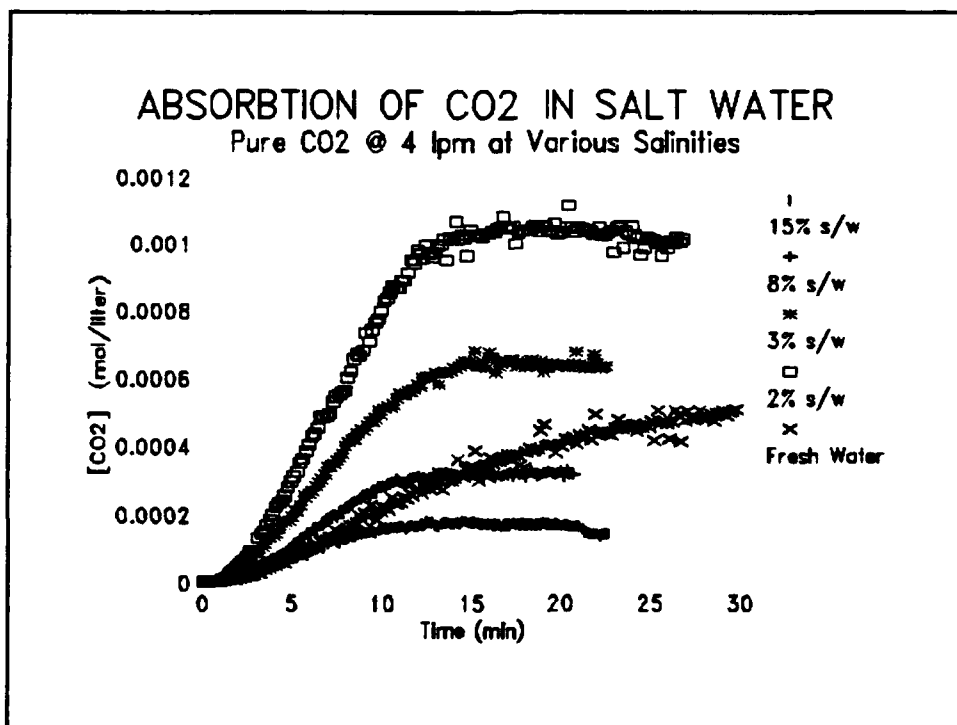


Figure 11 Comparison Seawater runs at Various Salinities

CONCLUSIONS

The primary conclusion which can be drawn from this project is that water has a great potential for future use as a scrubber. In almost every single test run, the concentration of carbon dioxide dissolved in the water increased considerably. Although some variables had a larger effect on that concentration, in all the runs, the original concentration of carbon dioxide was increased many times over. This makes it safe to conclude that the potential is there and it warrants future investigation. Some recommendations for future studies are provided in the next section of the paper.

In the first series of tests, it was found that by increasing the flow rate of the gas, the absorption of gas into the water was increased. This is clearly shown in Figure 9. This plot demonstrates that when there is less gas flowing through the water, less gas is absorbed. This is a logical conclusion because a higher flow rate equates to more surface area in contact with the water at one time. Thus, more gas can cross over into the surrounding water.

The last conclusion is made from the tests involving varying salinity. The addition of salt to the water reduced the surface tension of the water and allowed smaller bubbles to form. This caused an increased surface area for the dissolution process to occur. Yet, too much salt in the water tended to decrease the actual dissolution which

occurred. The highest absorbtion of CO_2 occurred in the test which only used 2% seawater. Figure 11 shows the comparison of water at different salinities. This graph also shows how the absorbtion curves for the seawater tests tended to level off around 10 minutes into the test. The decrease in bubble size drives the water to saturation at a much faster pace than the larger bubbles which exist in fresh water.

FUTURE WORK

There is definitely a need to continue the investigation of carbon dioxide absorbtion into seawater. Due to time constraints, very few of the tests were conducted using seawater. This would definitely be an area for further investigation. Another possibility is the use of carbonic catalysts to increase the absorbtion rate. A researcher might also consider investigating the theory behind bubble dissolution and produce a theoretical model for bubble cloud dissolution rates.

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Appendix A

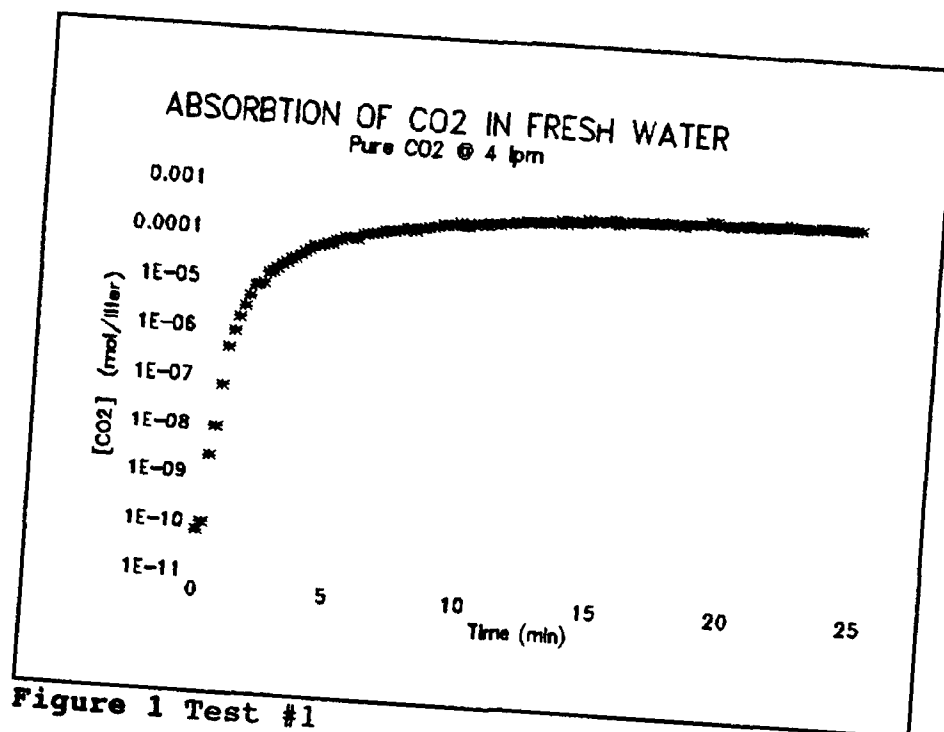


Figure 1 Test #1

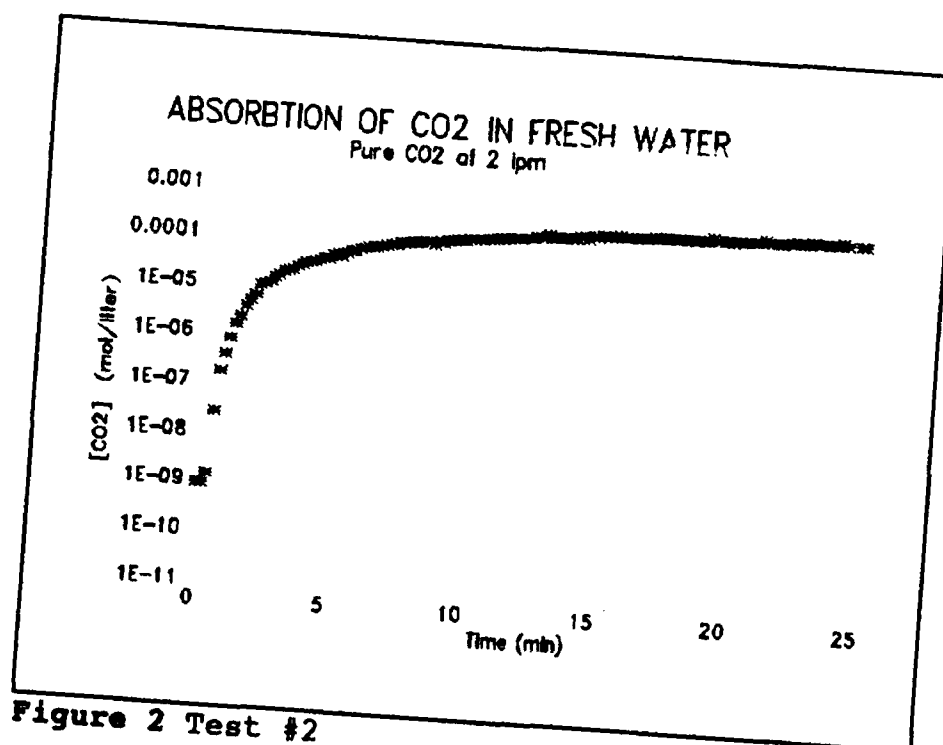


Figure 2 Test #2

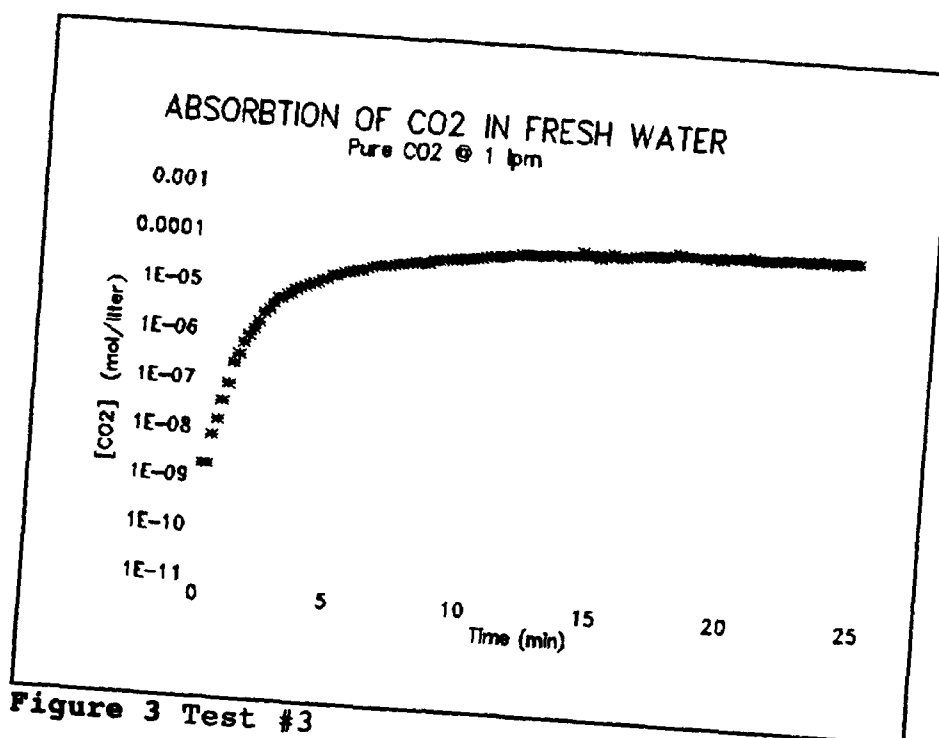


Figure 3 Test #3

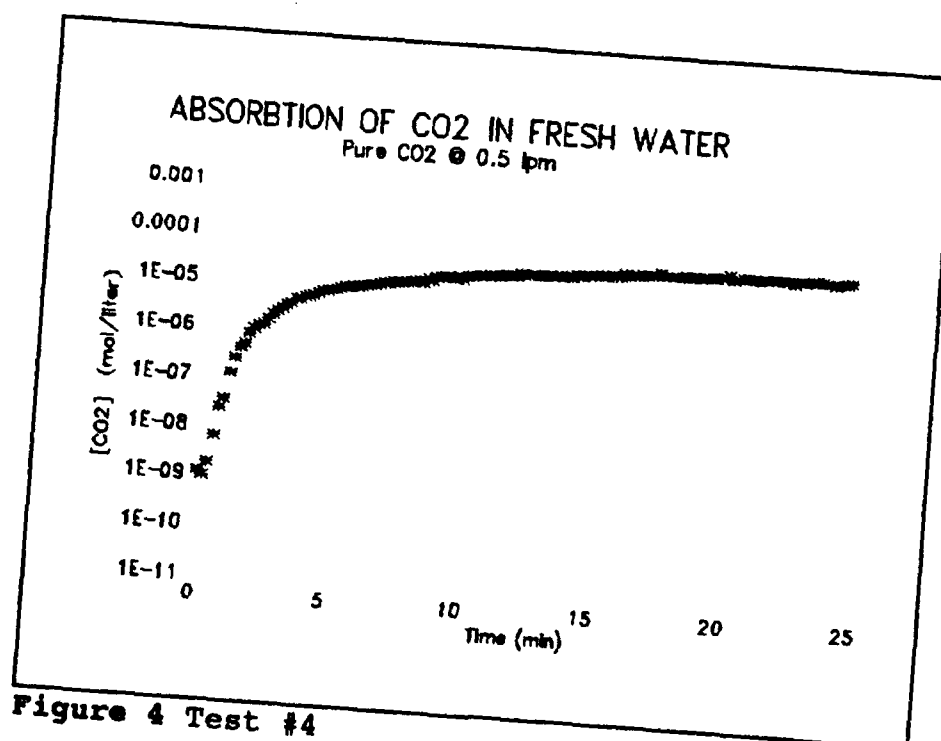
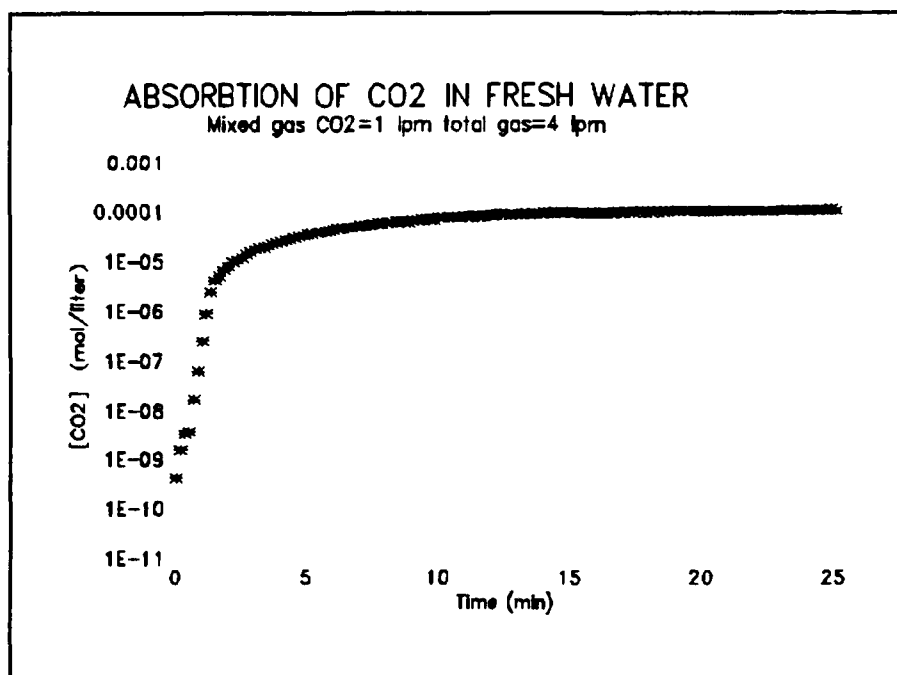
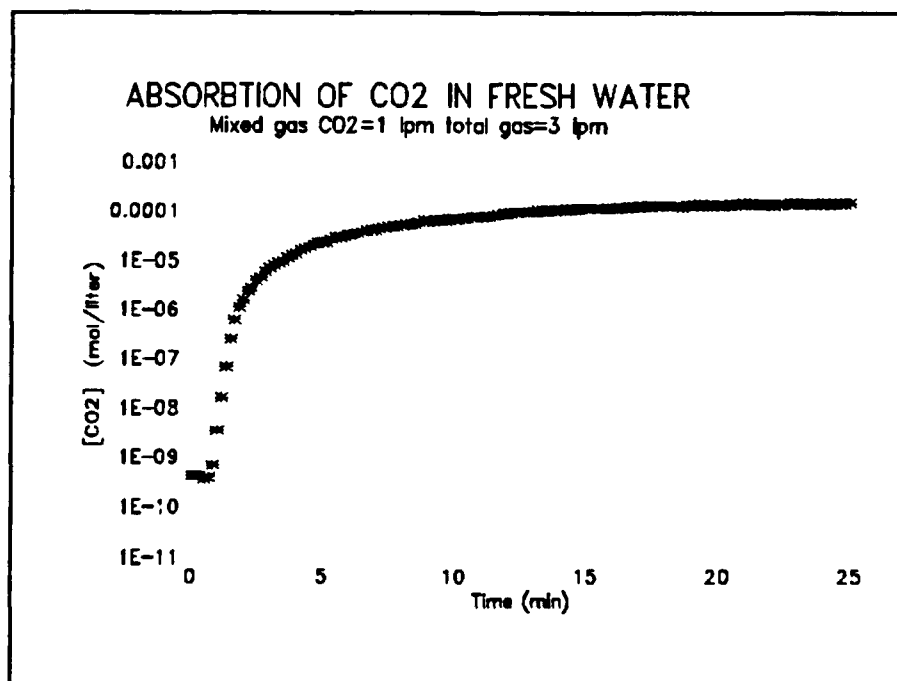
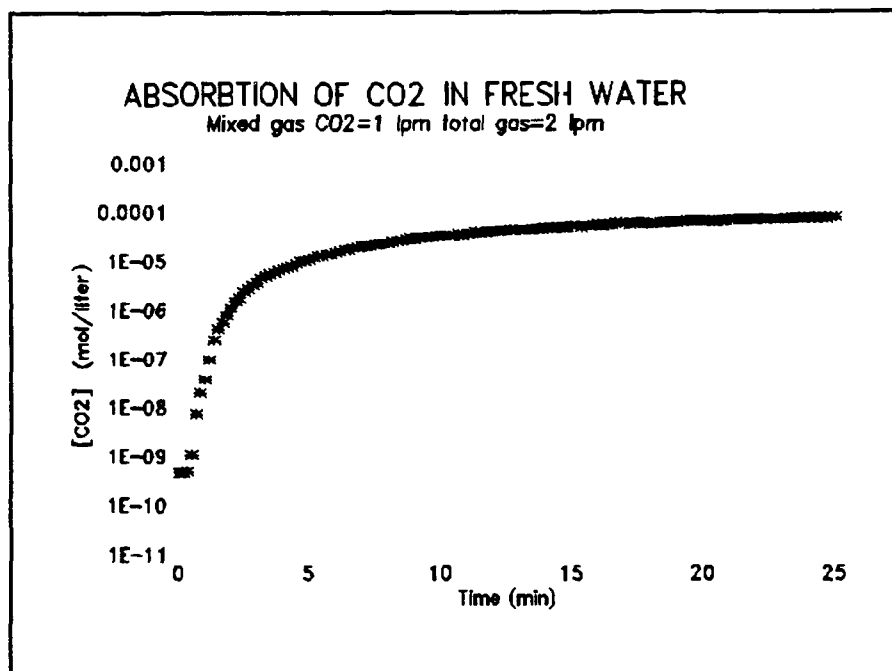
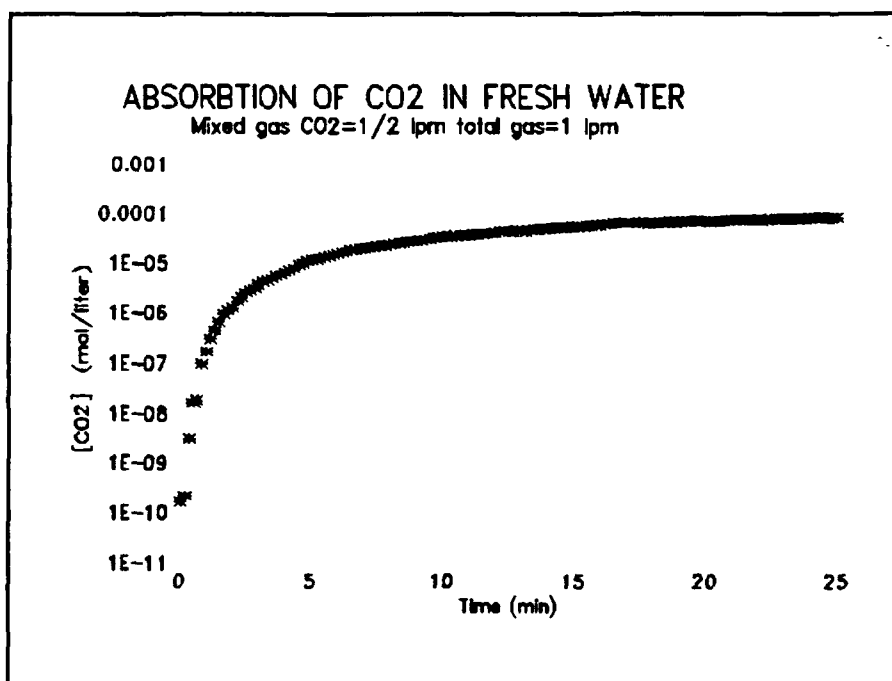
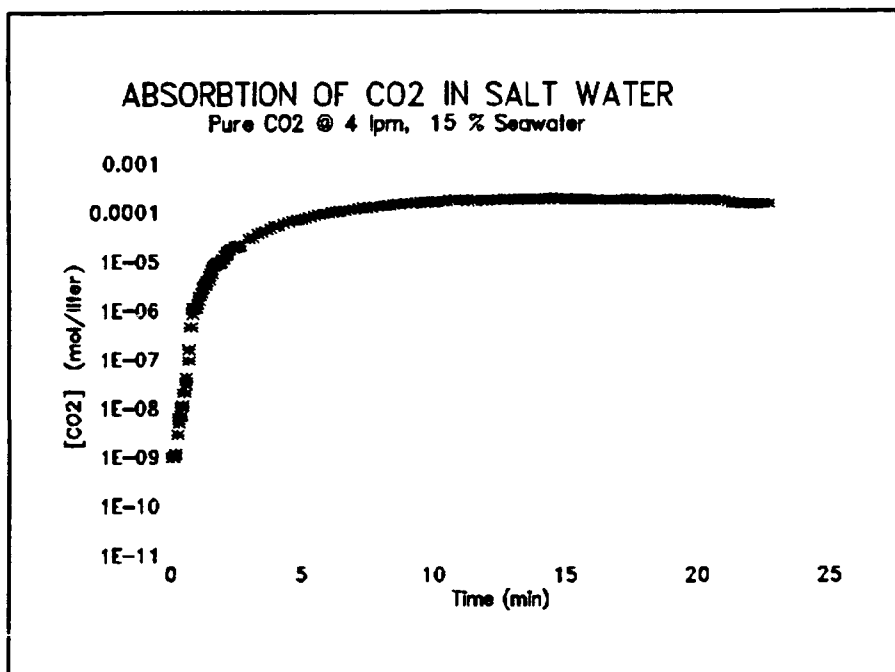
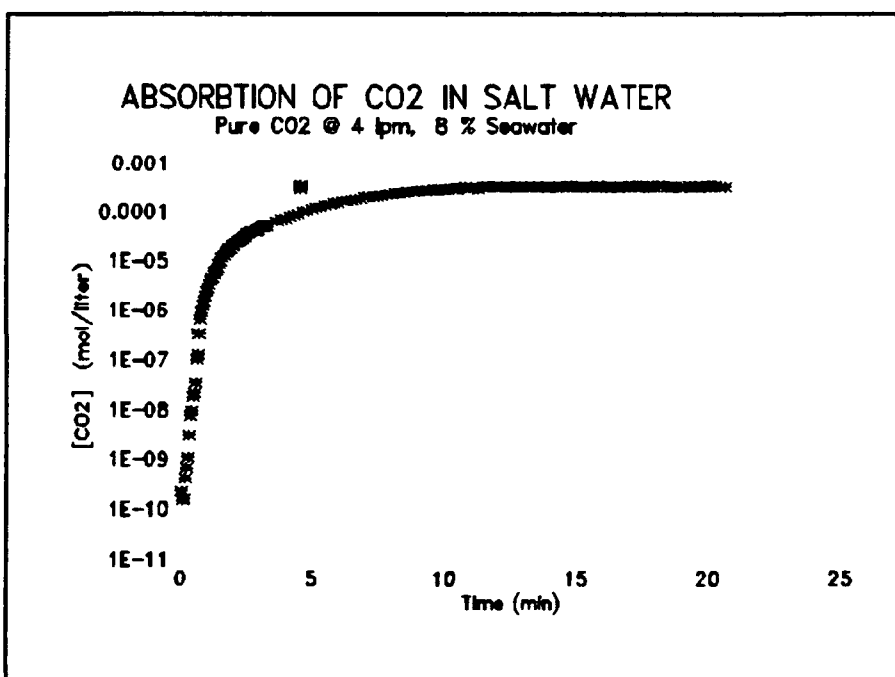


Figure 4 Test #4

**Figure 5 Test #5****Figure 6 Test #6**

**Figure 7 Test #7****Figure 8 Test #8**

**Figure 9 Test #9****Figure 10 Test #10**

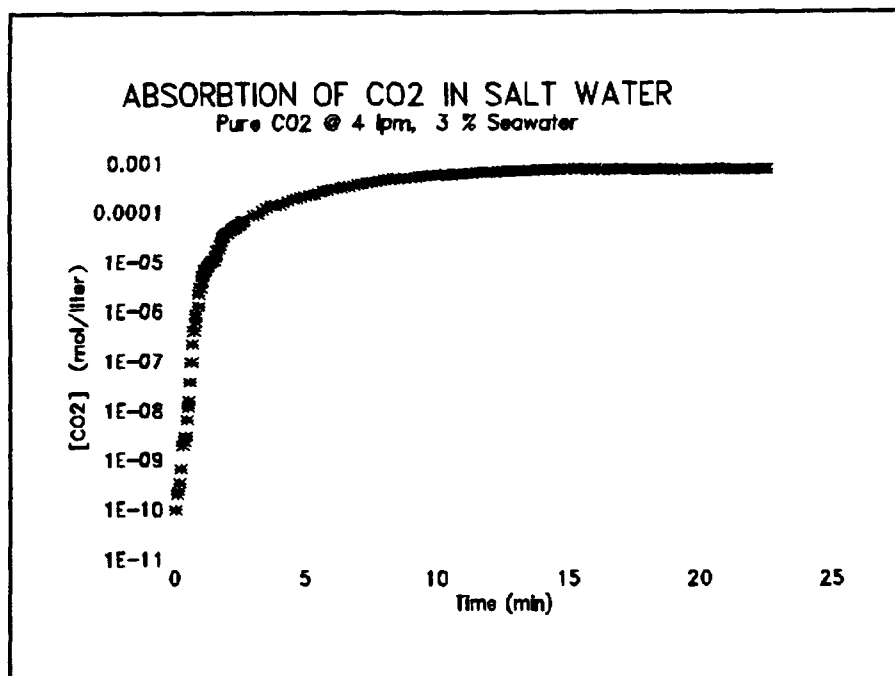


Figure 11 Test #11

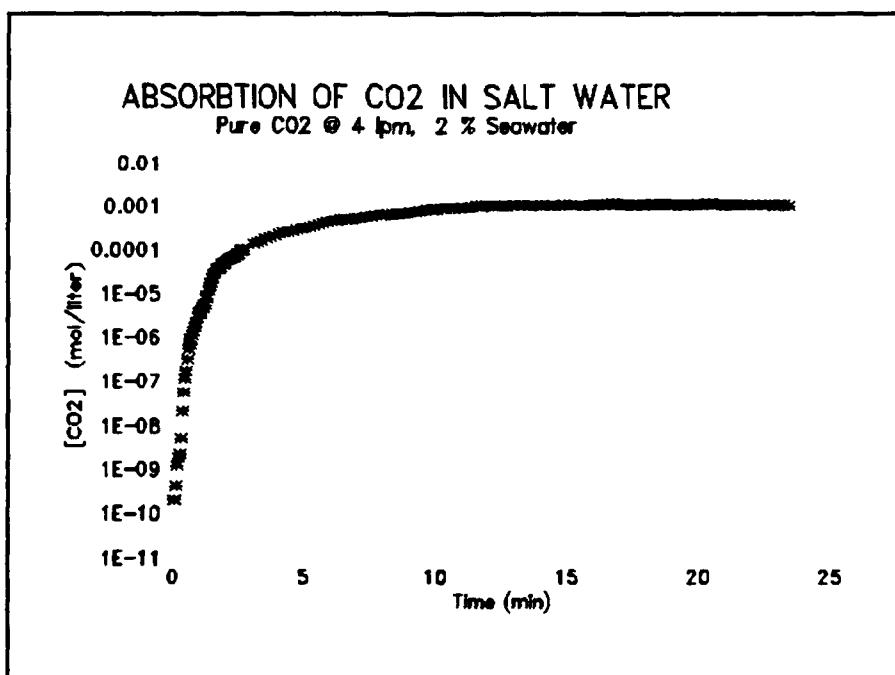


Figure 12 Test #12